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7.4.1 SIMULTANEOUS MULTIBEAM SOUNDING OF WIND AND TURBULENCE

T2312160

E. Brun and M. Crochet

LSEET
Toulon 83100, FRANCE

and

W. L. Ecklund

NOAA
Boulder, CO 80303

NJ920944

INTRODUCTION

Most clear-air radars use an antenna with either a few fixed beam positions or one that can be steered to a number of beam positions, one position at a time. For spatial studies of parameters that can change rapidly, such as C_n^2 (related to turbulence) or wind fields influenced by short-period waves, these conventional radars may be severely limited. The problem is that the fixed-beam radars do not cover enough positions and the steerable radars may not be able to cover the entire field of interest in a short enough time period. In this report, we present preliminary results from a brief experiment that suggests a way to overcome some of these space-time problems in clear-air radar research.

In September 1984, a typical clear-air radar antenna located in France was modified in a simple way to produce a number of beams simultaneously. In the following paragraphs, we describe the radar, the modifications and the resulting beam patterns. We then show spectra obtained with the multibeam array and present some results on the spatial variations of reflectivity. Finally, we summarize both the positive and negative aspects of using a multibeam antenna array for clear-air radar studies.

EXPERIMENTAL ARRANGEMENT

A 47.8-MHz clear-air radar (Provence) was installed at Termes d'Armagnac (West of Toulouse) as part of a coordinated experiment called Fronts 84. The radar used a 50 by 50 meter antenna comprised of 16 strings of coaxial-collinear antennas and phase shifters, so that the beam could be directed either vertically or 15 degrees east of the zenith. The 16 strings of antennas were spaced one-half wavelength apart, and groups of 4 adjacent antennas were fed by separate branch networks and phase shifter sets that were in turn fed by the main 4 to 1 branch and phase shifter set. In this way, antennas 1 to 4, 5 to 8, 9 to 12 and 13 to 16 were fed by separate branches.

In this experiment, the connectorized feed lines were changed so that the main 4 to 1 network and phase shifters fed only 4 selected strings of antennas out of a total of 16. For a spacing of 2 wavelengths between strings, we connected antennas 1, 5, 9 and 13, and for a spacing of 2.5 wavelengths, we used antennas 1, 6, 11 and 16. Figure 1 shows the calculated multibeam antenna patterns for 3 of the arrangements. The top pattern is for a spacing of 2 wavelengths with all four antennas in phase, and the middle pattern is also for a 2-wavelength spacing but with a progressive phase shift between antennas (the same phase shift that is used to form the 15-degree east beam in the full array). The bottom pattern is for a 2.5 wavelength spacing with all antennas in phase.

EXAMPLES OF MULTIBEAM DOPPLER SPECTRA

The data presented here were obtained over a one-day period (9 to 10 September, 1984). The radar was operated with all 3 beam configurations shown in Figure 1, and representative Doppler power spectra from each configuration are shown in Figure 2. The wind was blowing from the west during this period, and the spectral peaks due to each antenna beam are clear in the spectra displayed in Figure 2. These spectra were obtained at different times and heights, and the radial velocity scales are not the same on all three spectra. Note that the largest peak in each spectrum has been set to full scale. The point we want to make with Figure 2 is that if one has knowledge of the wind profile in the plane of the beams it is possible to identify the Doppler shift, spectral width and echo power associated with each beam by the relative position of each peak on the Doppler spectrum. The wind profile can be obtained from the oblique beam of the full array or by some other method such as balloon sounding.

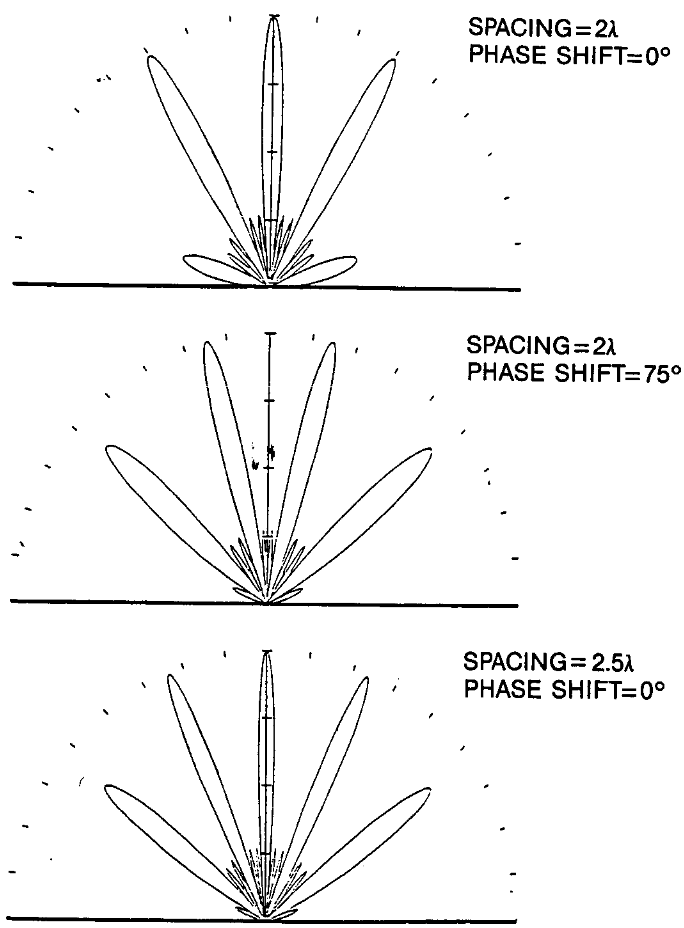


Figure 1.

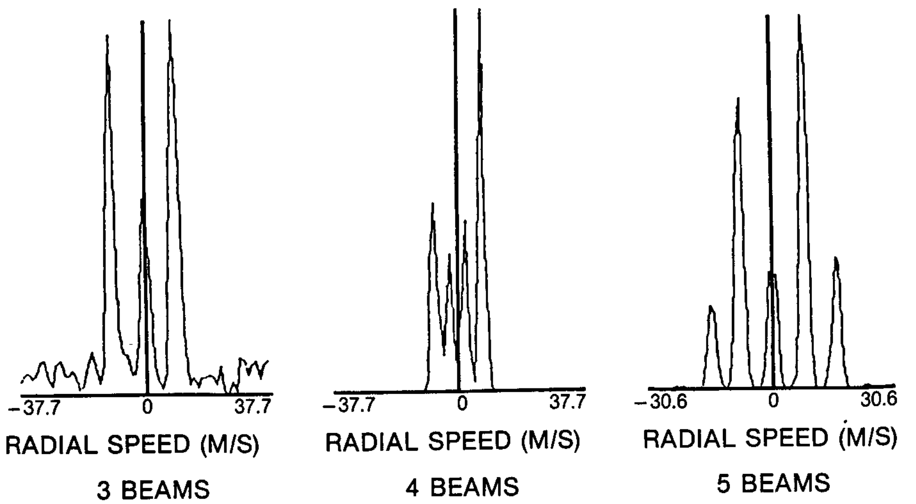


Figure 2.

EXAMPLES OF SPATIAL VARIATIONS IN ECHO POWER

For most of the short experimental period, we used the 5-beam configuration shown at the bottom of Figure 1. In Figure 3, we show a sample spectrum obtained with this arrangement. The peaks in the spectrum have been labeled 1 through 5. Peaks 1 and 5 are from the symmetrical antenna beams with zenith angles of about 52 degrees and peaks 2 and 4 are from the symmetrical beams with zenith angles of about 23 degrees. Peak 3 corresponds to the vertical beam.

Figure 4 shows a set of 3 spectra obtained over a 17-minute period that demonstrate large differences in the relative echo power observed in peaks 1 and 5 (peaks 2, 3, and 4 are just visible in the spectrum taken at 7:45 UT). Since the spectra were obtained from a range of 7 km, peaks 1 and 5 correspond to scattering volumes at a height of about 4.3 km and with a spacing of about 11 km horizontally (peak 5 to the west, peak 1 to the east). In the first spectrum at 7:28 UT, peak 5 is larger than peak 1 by a factor of about 5 in power, at 7:43 UT peak 5 is smaller than peak 1 by a factor of 5 and at 7:45 UT peak 5 is slightly larger than peak 1. These differences in echo power at two regions separated by about 11 km horizontally are very dynamic, suggesting a good deal of spatial structure in the related turbulence refractivity structure constant (C_n^2).

The spatial variations of echo power in 2 sets of symmetrical beams are displayed as a function of time for a 12-hour period in Figure 5. The ratio of echo power from peaks 1 and 5 is shown in the top plot, and the ratio of peaks 2 and 4 (Figure 3) is shown at the bottom. Ratios smaller than 1 have been inverted and assigned negative values. Peaks 2 and 4 correspond to scattering volumes at a height of about 6.4 km, separated by a horizontal distance of about 5.4 km. Peaks 1 and 5 correspond to volumes at about 4.3-km altitude, separated by about 11 km. Since the scattering volumes in the upper and lower plots are not at the same heights, we do not expect to see similarities in the 2 ratios due to patterns of enhanced C_n^2 moving across the beams. We note, however, that both ratios range from nearly plus to minus 10 showing that the relative echo power in each pair of symmetrical beams varies by a factor of 100 (20 dB) during the 12-hour period.

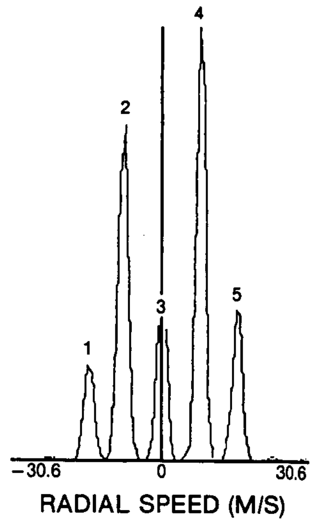


Figure 3.

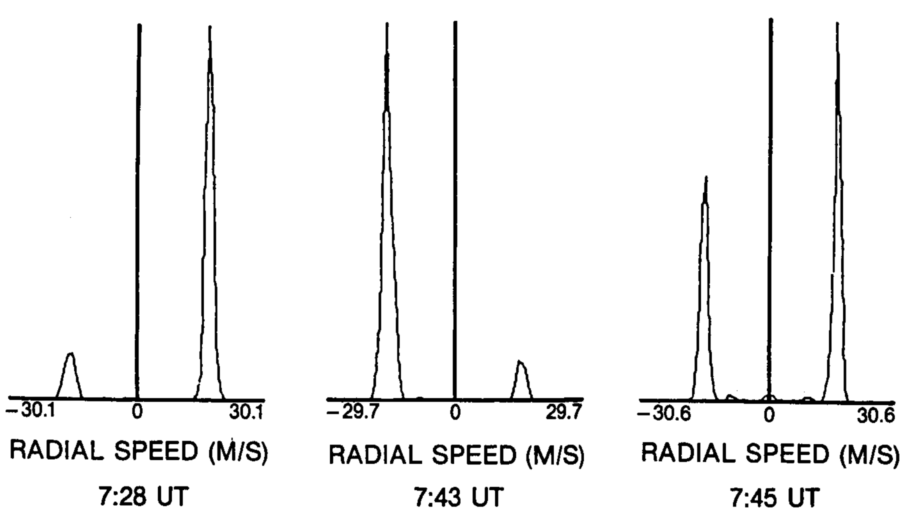


Figure 4.

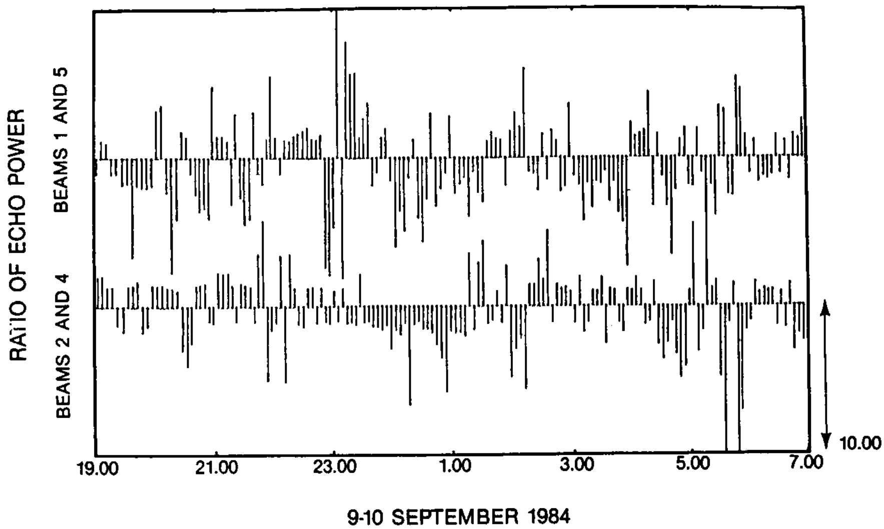


Figure 5.

EXAMPLES OF HEIGHT VARIATIONS IN ECHO POWER

In addition to the dynamic horizontal differences in echo power just presented, the multibeam radar also shows interesting differences in echo power on the different beams as a function of altitude. Figure 6 shows power spectra as a function of range taken with the 3-beam antenna. The central peak is from the vertical beam and the peaks on either side are from the symmetrical beams with zenith angles of about 30 degrees (see Figure 1). Note that the relative echo power in the vertical and oblique beams changes markedly as a function of height. At a range of 2.8 km, the oblique peaks dominate the vertical peak and at 5.2 km the opposite is true. This simultaneous comparison of vertical and oblique reflectivities can be used to infer the relative contributions of specular reflection and turbulent scatter as a function of height. The oblique peaks in Figure 6 correspond to heights lower than the range shown on the ordinate because of the slant range correction required for the 30-degree zenith angles of the oblique beams.

Figure 7 shows power spectra as a function of range taken on the 4-beam antenna. The spectra on the left were taken with a transmitted pulse length of 16 microseconds (2.4 km range resolution) and the spectra on the right were taken with 1-microsecond pulses (150 m resolution). Note that the 4 spectral peaks corresponding to the 4 beams are clearly evident at the lower heights in the left panel, but in the right panel the peaks are intermittent with height. This seems to indicate that the observed scattering is due to relatively thin layers of enhanced reflectivity. Since the spectra in the right panel of Figure 7 were taken with 150-meter resolution but are displayed at only 600-meter range intervals, it is not possible to trace the differences in the peaks at the inherent 150-meter resolution as a function of height. This example does, however, demonstrate the possibility of using the multibeam system to explore reflectivity structure with good height resolution.

SUMMARY

In this report, we have shown some preliminary results from a clear-air radar modified to operate with simultaneous multiple antenna beams. We think this approach has promise for special studies of turbulence and waves that require good spatial and temporal coverage. The technique should be ideal for momentum flux measurements. If one of the multiple beams is directed vertically, it is possible to compare both echo power and radial velocity on vertical and oblique beams at the same time. We have shown how an existing full array can be simply modified to provide multiple beams. It should also be pointed out that if the wind in the plane of the beams can be obtained by some other method, the multibeam antenna can be very simple, consisting of only a few antenna strings. This antenna would be inexpensive and easy to transport and install. Addition of a second set of antennas perpendicular to the first set would give up to 4 simultaneous azimuths if 2 transmitters were employed. In addition, the relatively low elevation angles of some of the symmetrical beams provide lower altitude coverage than is available from the normal, nearly vertical beams (but with poorer altitude resolution).

A major disadvantage of the multibeam array for clear-air radar use is the reduced sensitivity due to the decreased antenna collecting area. A simple antenna, such as the one used in this experiment, would probably limit the height coverage of most ST radars to the lower troposphere. Another problem is the requirement to know the wind in the plane of the antenna beams. It might also be difficult to uniquely assign all of the spectral peaks to their corresponding antenna beams if the wind field changes rapidly with height. The last problem is that multibeam data reduction is complicated by the fact that different peaks in a spectrum taken at a fixed range correspond to different heights depending on the corresponding multibeam zenith angles.

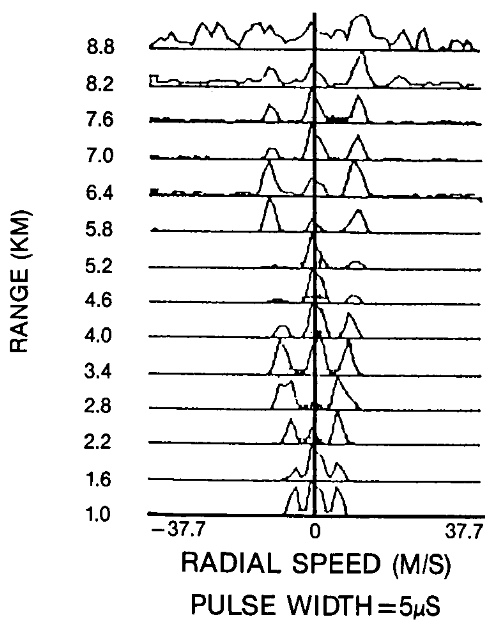
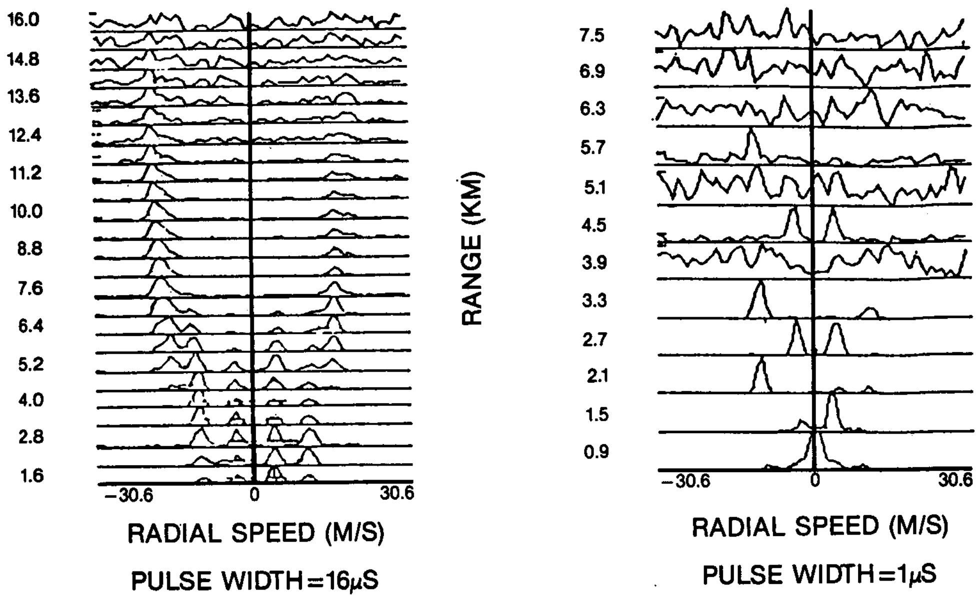


Figure 6.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14.8
13.6
12.4
11.2
10.0
8.8
7.6
6.4
5.2
4.0
2.8
1.6
−30.6
0
30.6
RADIAL SPEED (M/S)
PULSE WIDTH=16μS
RANGE (KM)
7.5
6.9
6.3
5.7
5.1
4.5
3.9
3.3
2.7
2.1
1.5
0.9
−30.6
0
30.6
RADIAL SPEED (M/S)
PULSE WIDTH=1μS

Figure 7.